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Simulating the Transport of Tritium for ITER with EcosimPro

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Abstract: *One of the objectives of the ITER project is to carry out a strict control of the inventory of tritium because of its radioactivity and the need to recover it on account of its being a very rare element on Earth. This paper presents how having simulation models can be a fundamental tool in determining the amount of tritium present in the different Test Blanket Systems.*

1. INTRODUCTION

The consumption of fuel used in the ITER reactor (tritium) surpasses both the amount available and the production capacity. Consequently, tritium production and recovery systems take on special importance in the ITER project. To that end, a number of different Test Blanket System (TBS) configurations have been proposed as systems for producing tritium. The simulation models of two of them (Helium Cooled Lithium Lead HCLL and Helium Cooled Pebble Bed HCPB) are presented as an engineering aid able to control the inventory of tritium.

Because of the diffusive properties of tritium, it is not easy to control its inventory. This makes it essential to use simulation tools to develop models that can study the transfer phenomena that take place.

The simulation tool used was EcosimPro due to its object-oriented nature, which facilitates implementation of these processes, the chance it offers of combining different disciplines (transport, hydraulic control, etc.) and the robustness of its problem-solving algorithms.

To make simulating more accessible to non expert users of EcosimPro, the models have been given an easy-to-use and intuitive MS Excel interface.

2. TEST BLANKET SYSTEM: HCLL AND HCPB

The TBS is the system in charge of generating tritium (in its main equipment - TBM) and recovering it by auxiliary systems so that this tritium can be used in the fusion reactor. Research activities in the field of TBMs have yielded several likely configurations of these systems for use in ITER. The modeling done in EcosimPro has focused on the two European configurations described below: HCLL and HCPB

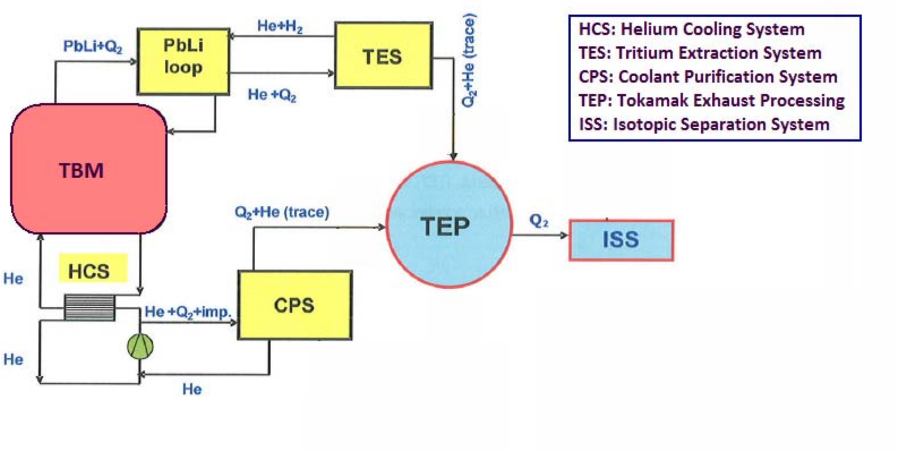


Figure 1. Diagram of HCLL-TBS. For the HCPB-TBS system the diagram is similar, eliminating the LiPb loop.

2.1. HCLL Test Blanket System

The HCLL configuration consists of three U-shaped metal channels through which liquid metal LiPb flows, which generates tritium when it is irradiated with neutrons. The channels are cooled by helium. The tritium is generated in atomic form and transported through the channels. Along its movement, the tritium undergoes permeation through the metal structure up to the coolant.

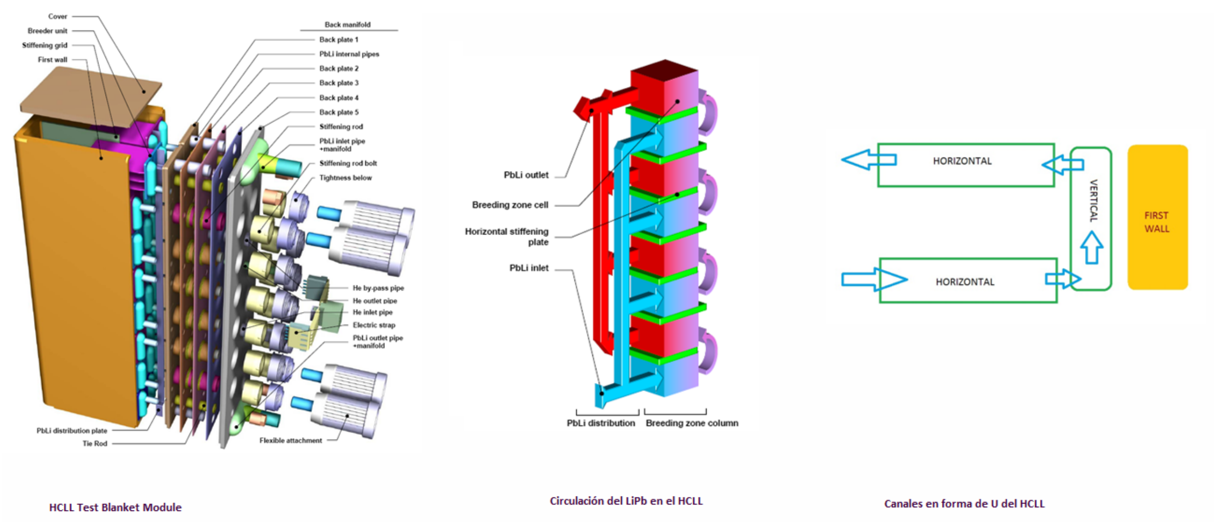


Figure 2. HCLL Test Blanket Module

To model the phenomena for transporting tritium along the different surfaces, the following series of resistances are considered:

- Liquid metal LiPb: this in turn considers the hydraulic flow of the LiPb along the channel, the generation of tritium and its diffusion in the normal direction of flow.
- End layer of LiPb: the LiPb metal adjacent to the material of the channel is considered as a static material through which atomic diffusion defined by Fick's law.
- LiPb - Eurofer end layer interface: in this case the transport of tritium obeys Henry's Law.
- Eurofer: Once again, Fick's law applies.
- Eurofer - refrigerant gas (helium) interface: this considers the phenomenon of recombining tritium with hydrogen atoms to form HT. The effect of dissociation is deemed negligible.
- End layer of gas (helium): this resistance was not considered in the simulation models, since a continuously moving gas does not give any resistance to permeation.
- Refrigerant gas: As with the LiPB, this takes into account the flow of gas and the permeation in the normal direction of flow.

2.2. HCPB

As in the previous case, HCPB consists of three U-shaped channels that contain a bed of ceramic spheres that produce tritium when irradiated with neutrons. The tritium atoms are entrained by the purge gas (helium) circulating through the channels.

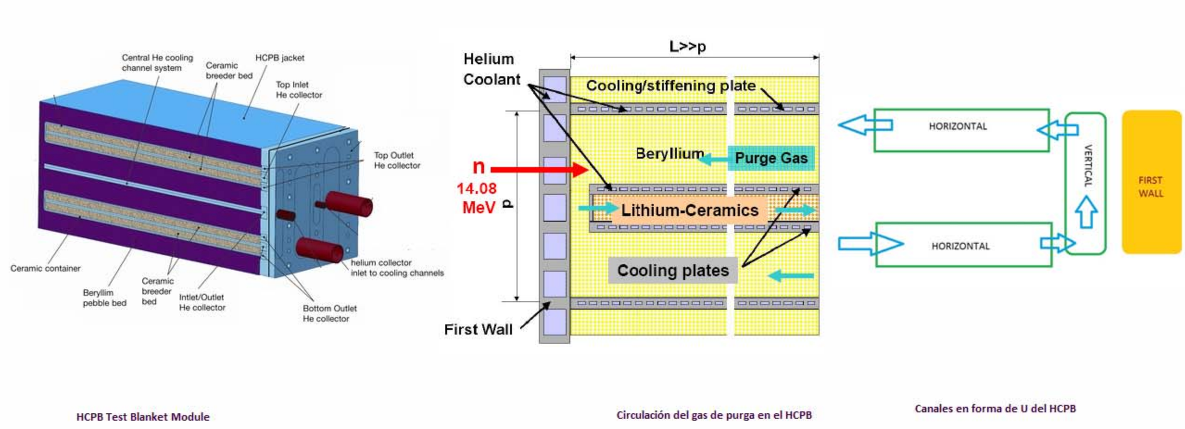


Figure 3. HCPB Test Blanket Module

The generated tritium stays for some time in the ceramic spheres, and is then desorbed and entrained by the purge gas. During the flow of this gas, the tritium permeates the structural material of the TBM (Eurofer) toward the refrigerant gas.

In this case the resistances considered in the simulation model are:

- Beds of ceramic spheres: this models tritium breeding and desorption as a function of the operating temperature and the characteristics of the material of the spheres.
- Purge gas (helium): This considers the flow of tritium due to the hydraulic movement of the gas, the desorption
- Purge gas - Eurofer interface: it is assumed that the diffusion of purge gas flows only toward the Eurofer, since the concentration of tritium in the refrigerant gas is very low.
- Eurofer: this models the diffusion through the material based on Fick's Law.

- Eurofer -refrigerant gas interface: The dissociation phenomena are considered negligible and only the recombining of tritium and hydrogen to form HT is modeled.
- Refrigerant gas: Resistance is modeled like the purge gas but without taking desorption into account.

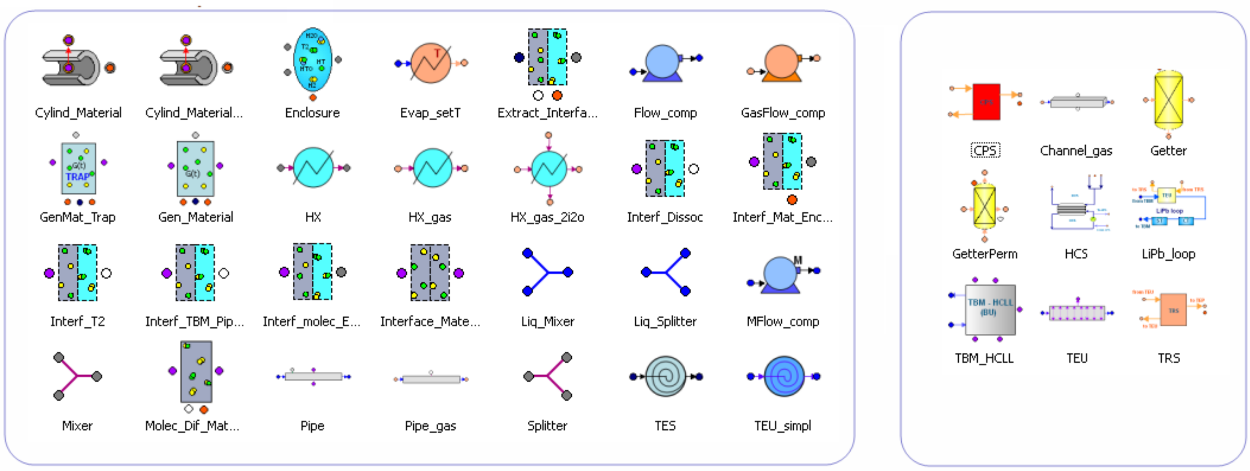
2. MODELING IN ECOSIMPRO

The TBMs and their auxiliary systems described in the section above were modeled using the EcosimPro simulation tool developed by Empresarios Agrupados. EcosimPro offers a number of major advantages given the fact that its object-oriented nature helps implement this type of process as well as being able to join different disciplines into one single simulation model.

The libraries developed under this software (**TRITIUM_LIBS**) contain all the components needed for constructing the HCLL-TBS and HCPB-TBS simulation models. These models can also be used to study how tritium diffuses through different materials, as well developing studies in transient, stationary and parameters.

The libraries developed are:

- TRITIUM_BALANCE: contains components to simulate the phenomena of transporting hydrogen isotopes.
- TRITIUM_TBM: based on the library above, it has units that conform the TBS systems, considering the generation and extraction of tritium.



Componentes de la libreria TRITIUM_BALANCE

Componentes de la libreria TRITIUM_TBM

Figure 4. Symbols of the TRITIUM_LIBS library components in EcosimPro

The final models are built by means of connecting the present components in the system and adding the operating values (temperatures, flows, materials, discretization points, lengths, rates of generation, etc.).

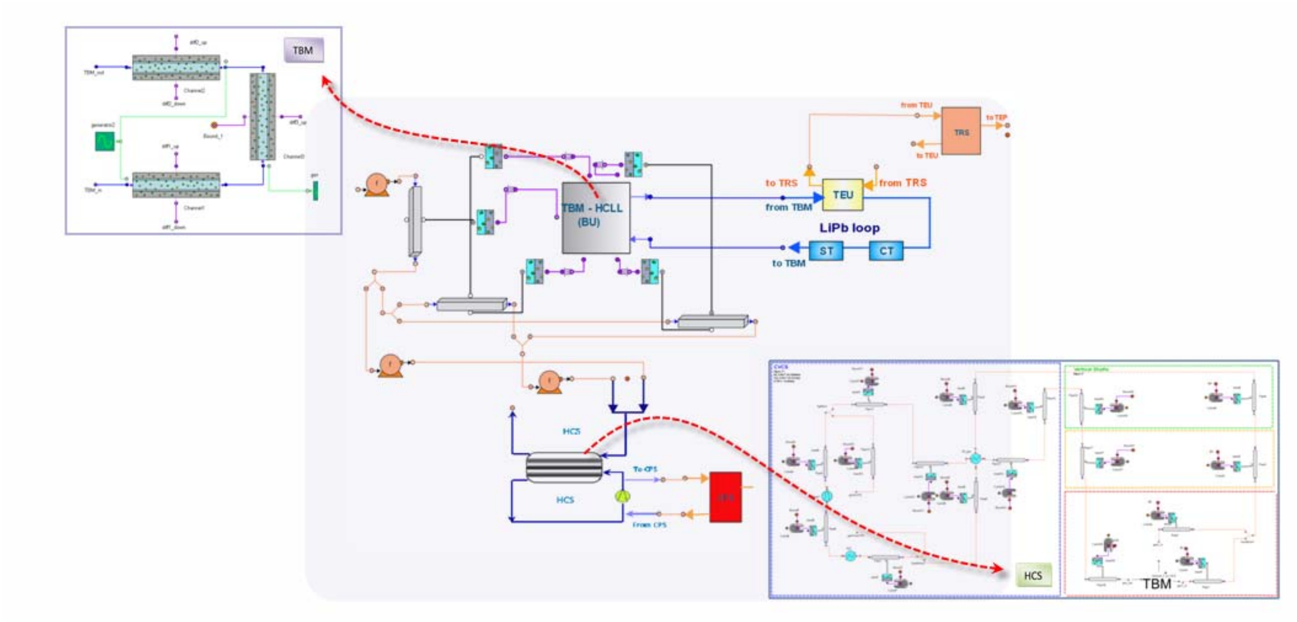


Figure 5. EcosimPro schematic diagram of the TBS-HCLL system

3. EXCEL INTERFACE OF THE SIMULATION MODELS

EcosimPro has the ability to connect the models developed with MS Excel so as to facilitate use the simulation by users who have no experience in EcosimPro. The advantages are as follows:

The opportunity of running simulations without having any knowledge of the simulation tools, and even without installing them.

The model is encapsulated so its equations cannot be modified, and any confidential information it may contain remains hidden.

-The interface is developed to allow access only to certain input variables than can be easily identified by the user, and certain output variables in function of the end-user's needs.

The possibility of easily representing the evolution of the results.

- The capabilities of Excel in handling data are added to the simulation power of EcosimPro.

Therefore, two interfaces were developed in Excel, one for each TBM configuration, in which access is given to the main input variables whose value can be changed by the user, and the output variables needed are chosen to carry out the tritium inventory study on the different TBS units. The interface also has a toolbar that can be used to launch the simulation, pause it, resume it, save a state, etc.

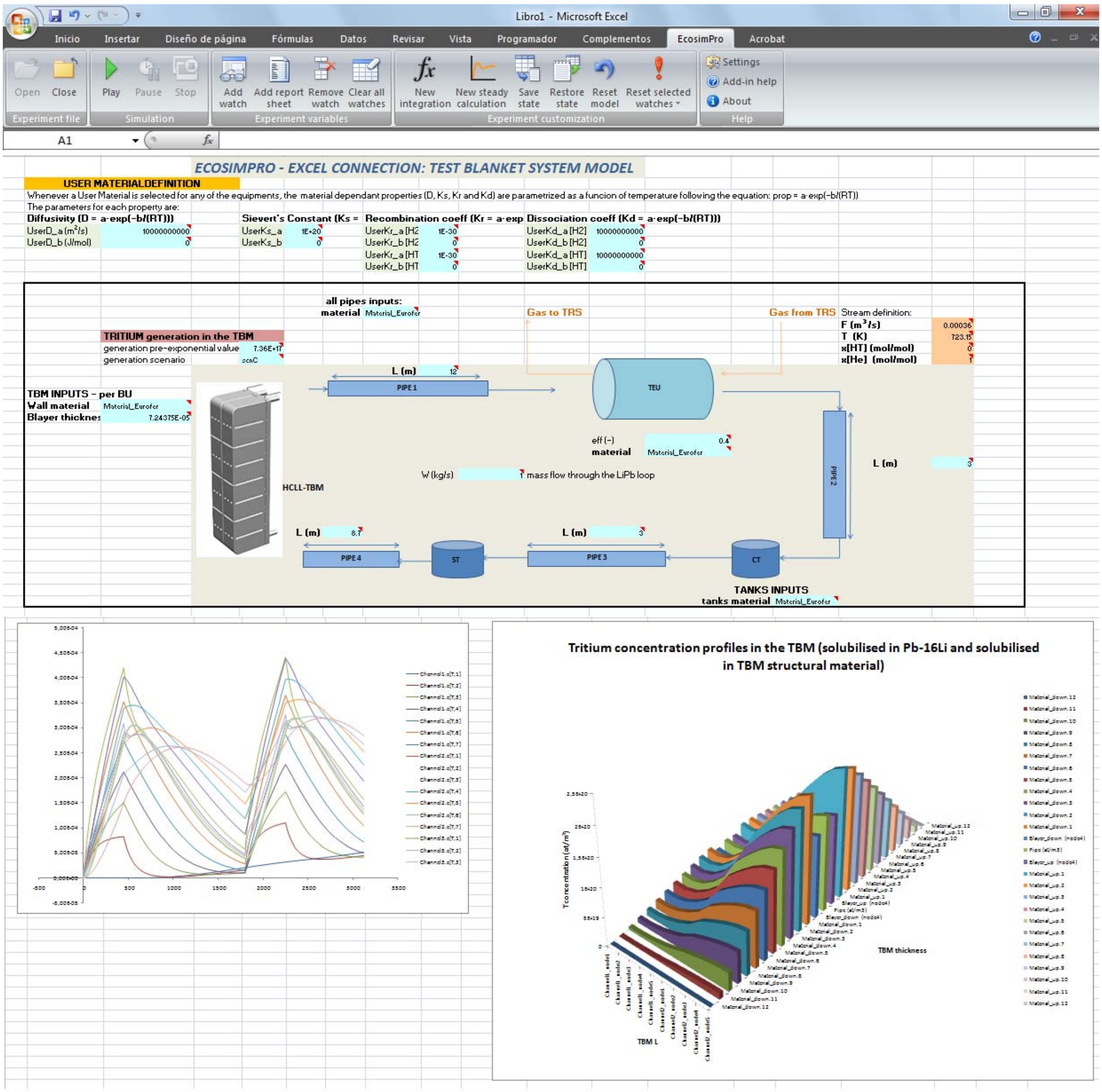


Figure 5. Excel interface for HCLL TBM

4. CONCLUSIONS

This paper shows the work done in EcosimPro to have simulation models that allow study of the tritium diffusion phenomena in two TBS configurations proposed in ITER.

EcosimPro is a strong contender for becoming the official simulation tool for modeling the tritium inventory in these systems on account of its object-oriented language (inheritance, encapsulation, aggregation) and of the robustness of its mathematical problem solvers.

It also offers the end-user the chance of providing an Excel interface to simulation such that access is only given to the variables needed to carry out the study on the tritium inventory.

ACKNOWLEDGEMENTS

Over the last five years, Empresarios Agrupados has worked with CIEMAT on the following projects regarding modeling and simulation of TBMs and the tritium plant.

- IDC-20101007: Tritium Plant simulator based on EcosimPro (TRITPLAN_SIM).

- F4E-GRT-254: Tritium Migration Modeling and Conceptual Design of the Tritium Accountancy Systems for the European Test Blanket Systems

- F4E-GRT-542: Upgrade of the Tritium transport simulation tool based on EcosimPro and generation of new simulation results

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